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DESIGN CONSIDERATIONS FOR A LUNAR INDUSTRIAL COMPLEX

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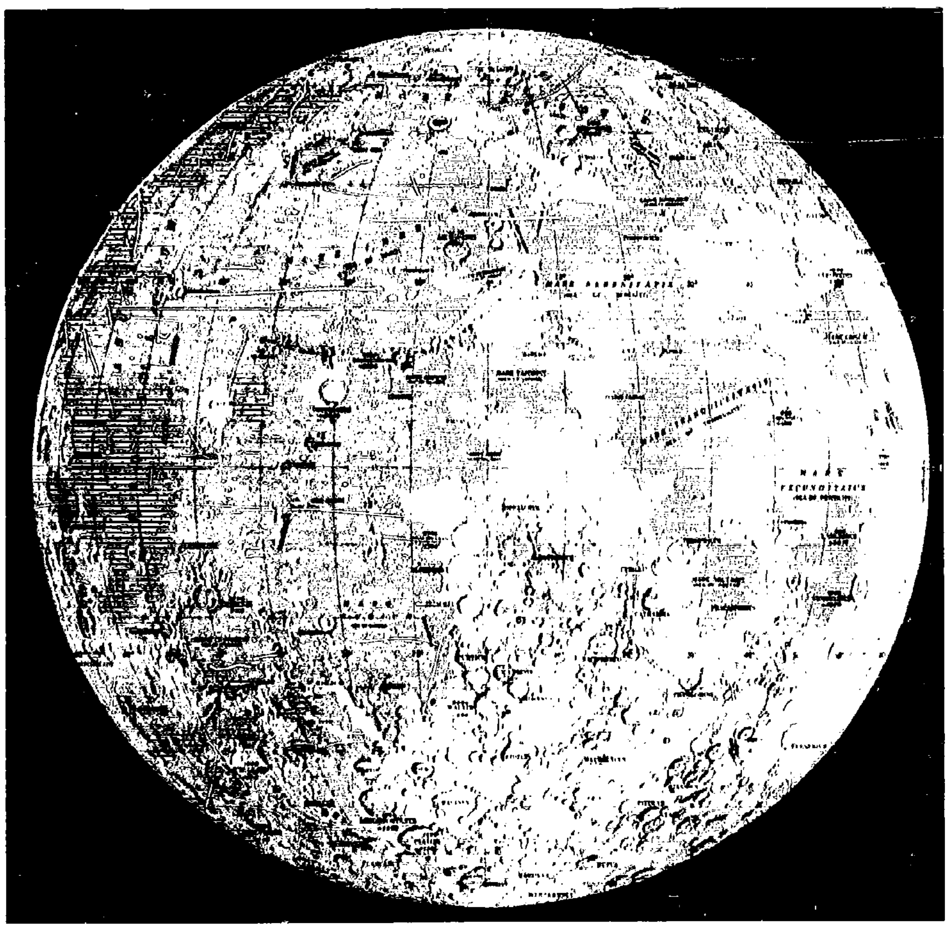
"Many improvements have been made by the ingenuity of the makers of the machines. ---- and some by those who are called philosophers, or men of speculations, ---- are often capable of combining together the powers of the most distant and dissimilar objects".

-Adam Smith, WEALTH OF NATIONS

INTRODUCTION

I plead an excuse for returning in great part to the theme of an earlier paper[1] for there is a growing realization that the biggest problems of interplanetary exploitation are much likely to be in terms more familiar to the statesman rather than the engineer, therefore I feel that reference to the political senses should be construed broadly to encompass all ethical, social and economic queries. It seems prudent at this time to state that the views expressed are simply my own and do not necessarily reflect any governmental opinion. Those wishing to indulge in the side choosing aspects of the moon's origin and surface composition will find Salisbury's work[2] and a forthcoming detailed survey of the literature and evaluation of the materials data and theories by Rostoker[3], an excellent reference source.

The successful exploitation of the lunar complex will depend in a large measure on the ability of the entrepreneur to seek and develop the natural resources with a minimum expenditure of energy. Therefore, it behooves us also to look critically at the selection of lunar sites which will satisfy most of the requirements such as the design of temporary structures which will enable



THE MOON, FIGURE 1

man to initially withstand the hostile lunar environment, yet be strategically located to the natural resources with safe spaceport access corridors.

The theme of this paper therefore is orientated to investigating these aspects and the probability of success in the economic and technical senses.

SELENOLOGY

A discussion of the planning of lunar bases is usually predicated on the nature of the moon, therefore it is desirable to give a brief description of the Selenology so that a common frame of reference may be established for the ensuing material. (Figure I)

The visible side of the moon has been carefully studied by a great many observers, and also by the USSR lunar probe which photographed the back side of the moon in 1961. (Wilkins and Moore have prepared an elaborate 300-inch map.[4]) Due to librations, about four-sevenths of the lunar surface can be observed from earth. The lunar surface is rough and mountainous. Surface features are classified as follows: The large level surfaces, generally dark and smooth in appearance, are called maria (seas), paludes (marshes) and sinus (gulfs), in order of decreasing size. There are bright plains, mountain ranges, isolated hills, uplands, peaks, valleys, gorges, clefts, and ray systems. There is also a great variety of structures such as walled-plains, mountain rings, ringed plains and crater rings. On the surface there are many craters varying in size from the resolution limits of terrestial instruments to fifty miles or more in diameter. These are divided into crater-plains, craters, craterlakes, crater cones, crater pits and certain faint rings and depressions.

The flat maria are many hundreds of miles in diameter and appear uneven when viewed with a large instrument. They seem to have a dun-like appearance and some places show evidence of subsidence.

The most important mountain range is the Lunar Apennines in the Northern hemisphere, bounding the Mare Imbrium, and rising to 18,000 feet with many high peaks. In the Southern hemisphere, there are many lesser ranges, the most important being the Leibnitz Mountains with peaks as high as 30,000 feet. There are about 2,000 clefts, which are chasms or cracks about a mile mide and sometimes hundreds of miles long. Estimates of depths vary from about 100 yards to approximately a mile.[5]

LUNAR BASE PLANNING CONSIDERATIONS

The notion of a base on the moon, or operating quarters of a more or less permanent and finally self-sustaining nature, has already received a certain amount of sober consideration. This is such a fascinating subject in all of its aspects that one may suppose that the number of speculators has been kept within reasonable bounds in times past only by the apparent impractibility of such a project. Recent events reveal that the United States government is sponsoring serious research and development of a lunar-base colony in this decade.

It is desirable then, in discussing lunar bases, that we establish parameters of constraints on our thought and objectively define a program for establishing the lunar colony, e.g.:

1. Design equipments for operations on a lunar surface to meet the indigenous operations requirements with minimum weight considerations in order to minimize earth-moon transport in the initial stages.

2. Determine the total mass transport requirements over specified time periods as a function of integrated base and component design.

3. Prepare a cost analysis of the entire project and attempt to amortize the costs in a feasible scheme.

The focal plan of lunar-base planning will concern methods of establishing small colonies by multiple sequential landings of equipment and men. Onec this is achieved, there will be an assembly of shelters and necessary equipment on the site, including the special earth-return vehicles. Colonization of the moon will commence with the selection of a site on the moon for the soft landing of men and material. The lunar landing vehicles will be of a modular design so that after they are collected together, they can then be assembled to form efficient and compact housing that would include living quarters, mess facilities, laboratories, shops, power stations, recreation or ward rooms and storage. Eventually a translucent dome could be built over the permanent housing and additional space acquired for hydroponic gardening or any other purpose.

ENGINEERING AND ECONOMIC CONSIDERATIONS

The establishment of a lunar base for refueling in flight vehicles has been proven necessary by many writers, Cole[6], Athas, etc. as a prerequisite for the successful accomplishment of the long-haul space missions to the remote planets in view of the fact that the characteristic velocities required for these missions are much larger than for the lunar flight. The two most accessible planets, (Mars and Venus) have characteristic velocities of 50 and 62 km/sec as compared with 32 km/sec for the moon. Since the characteristic velocities are the sums of the earth's escape velocity, the transfer from this orbit to that of the mission planet and the planet's escape velocity, these are, of course, doubled for the return trip home. It turns out equally for each case that the major item is the earth's escape velocity 11.2km/sec, the moon with its much lower velocity of 2.37 km/sec offers the energy savings of 8.8 km/sec for a single trip and about 17.5 km/sec for the return flight to another planet. This feature of moon refueling makes the long range moon-mars-moon flight possible with the same energy requirement as earth-moon-earth mission.

Space limitations in this paper preclude a lengthy discussion of what type of propellant is most efficient or what the alternate economic choices may offer in terms of capital return for the moon entrepreneur. However, I submit that the Lunar Industrial Complex will be free of political constraints and the major problems are similar to the terrestial location such as:

(1) Product and Market Demand

(2) Raw Material Source

(3) Plant Size

(4) Energy Requirements and Potential Power Sources

(5) Labor Force

(6) Amortization of the Lunar Autarky

PRODUCT AND MARKET DEMAND

The most vital product that man will need to sustain himself in the lunar environment is water. This life liquid and fundamental solution for the various chemical processes is also required in the lunar manufacturing complex. Water will also furnish two other major products, oxygen and hydrogen, which complete the life cycle and initiate the economic cycle for the Lunar Autarky.

Oxygen is essential and requires no further substantiation, however, it is interesting to note for the second time in the history of flight, man has turned his attention to hydrogen which now offers him advantages as a propellant fuel. The element hydrogen ranks ninth in order of plentifulness as compared with other elements on earth, however, the chemical abundance based on the number of atoms available for reaction places the element third in order of plentifulness which makes it an attractive candidate as a choice of rocket fuel. Hydrogen does not exist abundantly in the free state, but must be extracted in small amounts from volcanic exhausts and in certain rock and salt formations when not available in its most frequent form as a combination with the elements carbon and/or oxygen.

The production of terrestrial hydrogen is essentially a high energy consuming process and the lunar manufacturing techniques will be predicated on the same principles.

RAW MATERIAL SOURCES

Terrestrially hydrogen is found in the free state, in living matter, hydrides and water. The lunar environment, however, offers us only a faint hope of finding hydrogen in a free state unless it is trapped below the surface; ruling out living matter, coal and oil; it becomes clearer that water is the most attractive raw material source. The development of the argument is postulated on the availability of water in either free state or trapped in the igneous rocks. (Figure II)

The water choice is selected because of the tremendous energy costs associated with extracting occluded hydrogen from rocks such as may be native on the moon's surface. (Figure III) These rocks are well known on earth and it is evident that meteorites may contain hydrogen and other gases. Thompson[7] has looked at this aspect and concluded that such a scheme probably is impractical in view of the large amounts of materials that have to be handled in order to produce a sizable production lot. He showed that figures given for the occluded hydrogen in meteors and terrestrial rocks range from 0.2 - 1400 c.c. gaseous hydrogen per 100 grams of rock, some nitrogen, carbon dioxide also being present.

Assuming the range from 1-100 c.c. hydrogen/g. rock as a figure, this turns out to be about 0.009-0% by weight so that in order to produce one ton of hydrogen, one has to process on the same scale from 110 - 11,000 tons of rock. This in itself is a large measure of effort on earth and it seems

LUNAR WATER ORE MINER
FIGURE II

FIGURE III

PROBABLE COMPOSITION OF THE EARTH AND THE MOON[1]

Probable Composition of the Earth

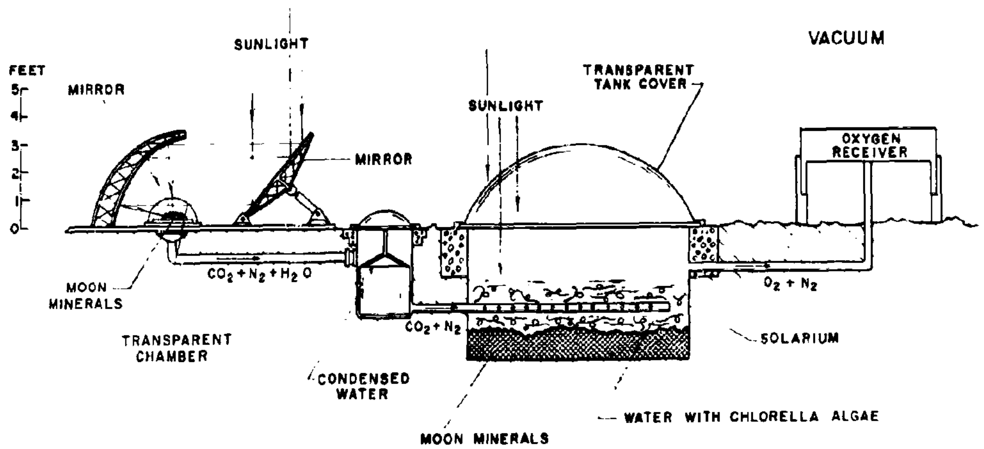
	MATERIAL	DENSITY G/CM^3	THICKNESS KM	VOLUME $10^{24} CM^3$	MASS 10^{24} GRMS
CRUST)	GRANITES	2.7	15	7.6	20.7
	TRACHYTES	2.7	37	19.0	51.3
	BASALTS	3.0	156	79.4	247.0
MANTLE)		3.4	1217	469.0	1597.0
CORE)		8.0	4946	508.0	4064.0
FOR THE GLOBE)		5.52	6371	1083.0	5980.0

Probable Composition of the Moon

	MATERIAL	DENSITY G/CM^3	THICKNESS KM	VOLUME $10^{24} CM^3$	MASS 10^{24} GRMS
CRUST)	TECTITES	2.7	26	1.0	2.7
	BASALTS	3.0	82	3.0	9.3
MANTLE)		3.4	1628	18.0	61.0
NO CORE OF IRON NICKEL					
FOR THE GLOBE)		3.33	1736	22.0	73.0

[1] From A. Dauvillier, "Le Volcanisme Terrestre Et Lunaire", (np).

An Installation for the Sustenance of Life on the Moon



Sunlight is focused on moon minerals in a vacuum-tight, transparent bell jar by a mirror combination. Water of crystallization (H_2O), carbon dioxide (CO_2), and nitrogen (N_2) are liberated from the minerals through the intense heating and conducted into a watery suspension of chlorella algae in a "lunar garden." Drinking water is also condensed in this container. The algae, with the aid of sunlight, "digest" the carbon dioxide and exude oxygen which—together with nitrogen and some remaining carbon dioxide—is collected in the tank at the right for breathing and other purposes.

FIGURE IV

impossible on the moon at this time in history.

The availability of water on the moon is currently almost as controversial a subject as the RS-70 aircraft. A large number of reliable sources, Levitt[8], Zwicky[9], Kopal[10], (Watson, Murray and Brown)[11], suggest that water is available on the moon, although it may appear as ice or in the rock. We are concerned here, however, with the energy extraction costs and their effects on the lunar industrial complex. I personally am of the opinion that we will be able to extract water from subsurface rocks with a yield of 5-18%.

PLANT SIZE

The design of a lunar manufacturing facility, particularly, one that is orientated to the production of liquid hydrogen will encounter many changed conditions from normal earth operations due to the smaller gravitational force of the moon. Large operating gravity type devices such as drop hammers, presses etc., are not of much value to the lunar technician. The major problem which is of great concern to the liquid hydrogen production man is still the storage and safety problem.

The "utilization factor" which denotes the overall efficiency factor of any liquid hydrogen system involving production, storage and handling is noted as the ratio of the quantity of liquid hydrogen available at the usage point to the quantity produced in the hydrogen liquefier. The many factors which enter into this point out the advantages for engineering design to enable the lunar operators to pump their product directly in space ship fuel cells or as soon as possible to preclude the loss due to vaporization. However, utilizing unique frozen subterranean areas as suggested by J. Harvell[12] may alleviate this problem. The space vehicles operating from each lunar site should consume the same fuel in order to eliminate purging of tanks for a non-homogoneous fleet and reduce the handling factor.

The typical terrestrial chemical plant is exposed to the elements, and the lunar site will have the same layout except that it may be necessary to shield the liquefication section from the sun for more efficient operations and conduct the liquefication cycle during the frigid evenings.

The size of the lunar plant will initially be small compared to the final design specifications in order to build for production on a concurrent basis, that is, provide lunar refueling facilities commensurate with the program requirements of the nation's space fleet and in the meantime concentrate on stockpiling the more critical items such as, water, oxygen, carbon, nitrogen, various metals and other chemicals.

ENERGY REQUIREMENTS AND POTENTIAL POWER SOURCES

The lunar manufacturing facilities will be somewhat unique among its terrestrial competitors in that every effort will be made to take advantage of the long periods of sustained sunlight with its plus 200 degree (F) temperature and a reciprocal minus 200 in the ice cold evening operations. This type of operation encourages a manufacturing design cycle which favors a diversified or sequential product line such as is suggested by Dr. Zwicky in the solar furnace approach. (Figure IV)

The theoretical production schedule for the lunar site to amortize the economic costs are established at one ton of liquid hydrogen per day. This is no simple task inasmuch as a 1500 lb/day operation on earth was considered an adequate accomplishment. Air Products "Bear Series" have this programmed capability to support certain Air Force requirements.[18]

The total energy requirements to product a ton of liquid hydrogen on the moon is postulated.

1. Processing net 9 tons of water at 10% efficiency from moon ore.	2,700 kwh
2. Process electrolytically one ton of hydrogen gas and eight tons of oxygen gas. (Assume 100% efficiency)	50,000 kwh
3. Process of liquefying the hydrogen gas using a Joules Thomas cycle with liquid nitrogen precooling at 17% efficiency.[13]	19,800 kwh
	82,500 kwh

The advantages of solar energy conversion schemes are many, but a quick look at the constraints may rule out a wide spread permanent installation. E.g., A solar furnace with an aperture of one square yard can collect and concentrate enough energy to generate 70 gallons of oxygen at atmospheric pressure from the dissocation of carbon or from water. This amount is sufficient to provide the average moon dweller with 60 hours of life. To supply water with the same scheme requires a solar furnace on the order of a 200-inch mirror to produce a mere six gallons of water from the lunar volcanic rocks.

The solar furnace certainly offers many advantages, but in view of the fact that the sun-Flux energy must be normal to the surface of the aperture to receive an approximate 130 watts per square foot, the weight considerations necessary to orient the aperture normal to the sun is painful, and of course, there is a night penalty factor to be considered.

The lunar power station requirements could be achieved by the electric field suggested by Dr. Castruccio[14] (1960) which consists of a thin plastic material coated with a tri-alkalide oxide sensitive to light, slightly separated and placed over a fine wire mesh. The sun heats the material which emits the electrons and they are collected by the wire mesh to yield about 1200 kilowatts per acre during the sun shining period. Stringing these around the moon suggest the beginning of "Moon Edison Electric" to provide service on a continuous basis.

The weight considerations necessary for the equipment to produce 100,000 kwh for the Lunar Autarky eliminates the feasibility of using large-area solar energy collectors. The engineering choice particularly above the 25,000 kw level is to select a nuclear power source for reliable, and consistent operations.

LABOR FORCE

A tentative number of ten colonists have been selected as the initial group as this number will provide redundancy consistent with the minimum requirements of operational nature.

The group will operate on a master-plan basis such as; set up the officer's club, mess hall, operation facilities, MARS station, and in due course of time, refine the initial plan and prepare for the next group of arrivals.

It is envisioned that the first group will be of a highly professional nature in order to assess the environment as soon as possible and also to establish an emergency source of food and essentials with the least possible delay.

AMORTIZATION OF THE LUNAR AUTARKY

The development and management of the Lunar Autarky should be viewed in the same light as any other large-scale operation. The major difference at this point is that the amount of funds required for the initial operation are not readily available to private industry. The theory of alternate costs can be applied when the merits of producing lunar fuels against the total costs of transporting earth stocks are examined. It is recognized that the tenets of monopoly will be exercised by the first forces that establish a colony on the lunar surface. (Figure V)

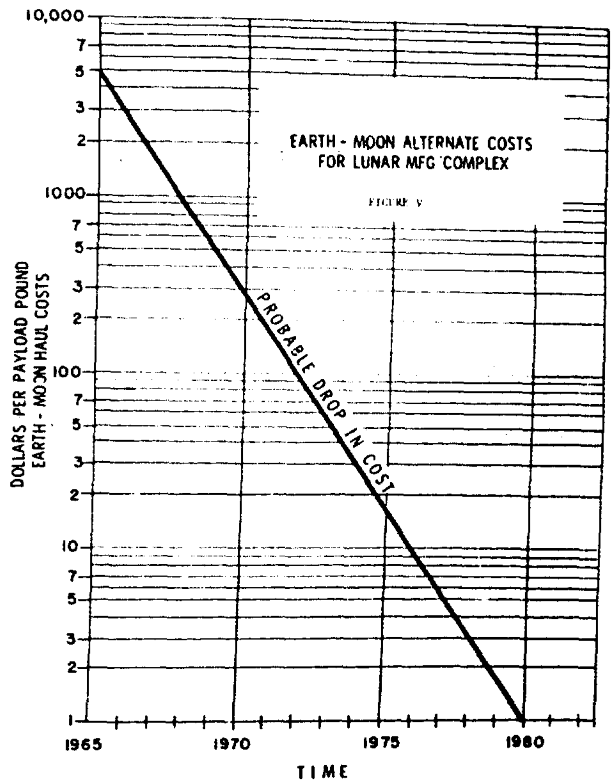


FIGURE V

For example, assume that the additional costs to transport the initial equipment and establish the initial lunar hydrogen processing plant is one billion dollars and the entrepreneur will be able to secure raw material and prime energy power at no cost. It is convenient to project a capital recovery figure based on a 10 year amortization period at six percent interest.

The operators will have to repay the lenders $135,870,000 each year for 10 years. The output of the plant in 1965 is priced at $5000/lb (alternate costs of shipping one pound of payload from earth stock). With this figure, the operator must produce only 27,154 lbs or 14 tons to break even for the year.

Since the plant is geared for full production in 1970, fuel is still about $300.00 a lb or $600,000 a ton, the breakeven part is now at approximately 226 tons. If the operator has a full demand schedule, his years profit is (365-226) = 139 x 600,000 = $83,400,000 for 1965.

It appears that the lunar venture can develop into a rewarding one for the courageous entrepreneur.

CONCLUSION

The Lunar Autarky can be self-sustaining based on its ability to produce a product such as liquid hydrogen for a cost ranging from $3,000.00 a pound in 1968, decreasing to $200.00 a pound in 1975[15], and will remain competitive with the terrestrial manufacturer until the cost drops below 25 cents (present U.S. costs), plus transport to the lunar surface. The application of the economic principle of alternate costs to the hypothetical energy costing theorem serves this statement. As long as the energies required to extract and transform the lunar resources into a useful terrestrial product are less than the energies required to extract these same products from the earth and transport them to the lunar surfaces, then the lunar industrial complex is in a favorable competitive position with its terrestrial competitor. The marginal return from each pound of liquid hydrogen or similar product will serve as the amortizing agent in the cost-accounting scheme of the Lunar Autarky.

PHOTO CREDITS

Lunar Map
USAF

Lunar Miner
Republic Aviation Corp

Solar Energy Furnace
Dr. Fritz Zwicky

REFERENCES

1. Athas, William C., Masters Thesis, University of Chicago, August, 1961, "Economic Considerations for the Self Supporting Industrial Complex in a Lunar Environment".

2. Salisbury, John W., Articles "Lunar Natural Resource" and "The Moon" Air Force Cambridge Research Laboratory, 1961.

3. Rostoker, David, Unpublished Papers, Arthur D. Little Co., Cambridge, Mass.

4. Wilkins, H. P. and Moore, P., The Moon, New York, MacMillan Company, (np).

5. Holbrook, R. D., Lunar Base Planning Considerations, Rand Corporation, February 24, 1958, Page 1436.

6. Cole, Danridge M., Response to the Hypothesis, Astronautic, June 1961.

7. Thompson, G. V. E., The Lunar Base, Journal of the British Interplanetary Society, Vol 10, No. 2, March, 1951, Page 58.

8. Levitt, I. M., Director, The Fels Plantearium of the Franklin Institute. Article, The Lunar Spaceport. (Private Communication).

9. Zwicky, Fritz, Professor of Astrophysics, CalTech, Possible Operations on the Moon, April, 1961 and (Private Communication).

10. Kapal, Zdenek, Professor of Astronomy, Manchester University, England. Article, Evening News, Newark, N. J., December 24, 1961.

11. Watson, K., Murray, B. & Brown, H., On the Possible Presence of Ice on the Moon. Journal of Geophysical Research, Vol. 66, No. 5, May 1961, Pages 1598-1600.

12. Harvell, John, Arthur D. Little Co. Cambridge, Mass. (Private Communication).

13. Webster, T. J., & Smith, K. C., Liquid Hydrogen Production on the Industrial Scale. Journal of the British Interplanetary Society, Vol. 18, September-December 1961, Page 169.

14. Castruccio, Peter, IBM Corporation, Washington, D.C. (Private Communication) 1962.

15. Von Braun, Werner, Space Propulsion Technology, Hearings before the Committee in Science and Astronautics, March 6-10, 1961, Page 163.